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THE RELATIONSHIP OF STATIC STRENGTH TO STRENGTH-IN-ACTION

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Relationship of Static Strength to Strength-in-Action" submitted by George S. Shaw in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

This study was designed to investigate the relationship between the effective static strength (represented by the strength/mass ratio) of the right arm computed at certain designated positions (0°, 45° and 90°) on a simulated horizontal arm-movement arc, and the strength-in-action of the same limb represented by the movement time through 90° of the same arc. The movement arc was described as a horizontal (lateral) adductive arm swing from side extension.

The reaction time (R.T.) and movement times (M.Ts.) of the horizontal adductive arm swing through four timing stations (22.5°, 45°, 90° and 112.5°), the effective arm mass, and the static strength (at 0°, 45° and 90°) were collected from fifty male university freshmen.

The correlations between the cumulated movement time to 90° and the strength/mass ratio at 0°, 45° and 90° were not significant at the .05 level of confidence. The correlations between the same movement time and the static strength scores at 0°, 45° and 90° were significant but low.

The inter-correlations between each of the raw static strength scores at the three tested positions were also significant. It was observed that as the sites of measurement became further apart on the movement arc, the measured static strength became more specific to the tested position.

No significant relationship was found between static strength or the strength/mass ratio and speed of reaction. Similarly, the correlation between speed of movement and reaction time was also non-significant.

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STATEMENT OF THE PROBLEM

Introduction

Recent research findings tend to dispel the traditional assumption that strength and speed are highly inter-related. These investigations have shown that the calculated strength of a limb used in making an all-out movement (strength-in-action), and the measured static strength of the same limb are quite different.

Investigation of this apparent difference in strengths led Henry to hypothesize extreme specificity of strength performances to the end that every "strength" has a distinct neuromotor coordination pattern and further, that these patterns are not related (1). Thus, static strength has a particular neuromotor coordination pattern, and strength-in-action, represented by the time taken to move the arm through a prescribed arc, has a different neuromotor coordination pattern.

The results of this study (1) and others (2, 3, 4, 5, 6, 7, 8, 9, 10), all of which report little or no relationship between static strength and strength-in-action, support the current theory of neuromotor specificity with respect to all forms of motor coordinations.

In all of the above-mentioned research, the movement pattern studied consisted of a lateral (horizontal) adductive arm swing from side extension through to the mid-line of the body. The static strength of the involved limb muscles was measured at the side extended position, i.e., the beginning position of the movement.

An anatomical examination of the side extended position of the

arm reveals that the muscles are unfavourably disposed towards applying optimal tension patterns in the direction of the intended movement.

In the side extended position, the involved muscles are exerting their tension across the pivot point of the shoulder, i.e., the shoulder joint, and at the same time attempting to move the arm at approximately right angles to the tension exerted, i.e., the lateral movement.

As progression along the movement arc occurs, static strength scores are determined by exerting tension from the same muscles. However, the tension developed will now be more closely applied in the direction of the attempted movement because of the anatomical placement of the limb.

With this observation in mind, the question arises: will the static strength, measured in a more anatomically favourable position on the movement arc, reveal any appreciably larger relationship to the strength necessary for movement through the same arc?

It would seem apparent that quantitative examination of these relationships must be carried out before complete confirmation of the specificity of strength hypothesis is possible.

Statement of the Problem

The purpose of this study is to investigate the relationship between the effective static strength (represented by the strength/mass ratio) of the right arm computed at the various designated positions on the movement arc, and the strength-in-action of this limb (represented by the movement time through 90° of the same arc).

The data available will also permit investigation of the following sub-problems:

a) the inter-relationships of measured static strength in the various designated positions on the movement arc;

b) the relationship between these various static strength scores and the reaction time; and

c) the relationship between movement time and reaction time.

Since findings to date indicate a lack of relationship between the variables in question, it is, therefore, hypothesised, that in the present study, measurement of static strength in a more anatomically favourable position will not show a significantly higher relationship to strength-in-action.

With respect to the sub-problems, it is anticipated that the findings will agree with existing published results of extreme item specificity.

Limitations

This investigation is limited by:

1) the sample, which will consist of fifty male volunteers enrolled in the University of Alberta freshman physical education service program;

2) the apparatus which provides testing of the right arm only;

3) the subjects' age, ranging from seventeen to twenty-five years of age;

4) the nature of the task which is a movement consisting of an horizontal adductive arm swing from side extension to past the mid-line of the body; and the static strength scores measured at 0^{o}, 45^{o}, and 90^{o} on the movement arc; and

5) the calculation of the effective limb mass, measured from the axilla to the proximal end of the third phalange of the right hand.

Definitions

a) Static Strength: The maximum tension created by a voluntary "all-out" contraction of the involved muscles is construed as the available static strength for any one trial.

b) Effective Arm Mass: This is the measured weight of the right arm taken from the axilla to the base of the third phalange.

c) Effective Static Strength: This is computed from the Strength/Mass ratic which represents the variable of static strength in the analysis with strength-in-action.

d) Strength-in-Action: The strength used to move the arm in a prescribed movement as fast as possible is designated strength-in-action. Strength-in-action is in actuality the force that the individual is capable of producing. This force (dynes x 10^{-6}) is represented by the formula $F = ma$. However, the results of Whitley and Smith (10) lead them to conclude that the relationship between static strength and action strength can safely be estimated as the correlation between static strength and speed or change in speed. Therefore, for the purposes of this study, strength-in-action will be represented by the recorded movement time.

e) Movement Time: The quickest voluntary time taken to move the side extended arm in an horizontal adductive movement from side extension through 90° in response to a light stimulus is construed as the movement time.

f) Reaction Time: This is the elapsed time from the onset of the stim-

ulus light to the initation of the movement.

g) Neuromotor Coordination Pattern: This represents a cortical engram programmed as a result of training which, upon receipt of a specified and definite set of stimuli, elicits a prepared response which is transmitted to the effectors to perform the designed act.

h) Movement Arc: The plane through which the extended arm moves from the beginning position at shoulder level side extension in an horizontal adductive pattern toward and past the mid-line of the body is the prescribed arc. Static strength is also taken at the designated positions on this arc.

i) Individual Differences:

> "Individuals vary in behavior as between one another and also within themselves. Inter-individual differences which are usually just called individual differences, consist of the variance between individuals that would be observed by the true scores. (A true score being the average of an infinite number of scores for that individual).
>
> Intra-individual differences consist of variance due to functional changes within the individual exclusive of error variance (variable instrumental error, observation error etc.). Because it is often difficult to separate the intra-individual and error variances, they are usually pooled and the total called error variance. Individual differences of both types as well as error variance, contribute to the sampling error of a population mean." (11)

j) Item Specificity and Generality: When reliable individual differences in two tested variables have been established, that which is found common to the two variables as a result of correlation, is referred to as the percent generality and is determined by the squared coefficient (r^2). The remainder of the variance not accounted for is termed item specificity and is designated k^2. These entities comprise the formula $1 - r^2 = k^2$.

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CHAPTER II

REVIEW OF THE LITERATURE

The realm of tests and measurements in Physical Education has, in the past, been dominated by the constant search for methods of measuring various physical attributes. The concern of some researchers has been to find an adequate, but simple and easily applied test for a "not-so-simple-to-measure" physical attribute, whether it be a balance ability or the strength required to throw the discus.

Within the confines of the field of muscular strength testing, and especially the muscular strength of the shoulder girdle (which is the interest of this study), investigations have been conducted to determine whether the static strength of a group of muscles could be used to predict the strength-in-action of the same group of muscles. It is assumed, on the basis of the argument presented by Whitley and Smith (1) and Henry and Whitley (2), that the maximal limb speed, which is proportional to the force/mass ratio, may be considered a relative measure of the strength-in-action.

Static Strength As Related To Strength-In-Action. The studies referred to use the horizontal (lateral) adductive arm swing pattern from side extension to obtain the necessary static strength and speed of movement data. The relationships observed have been relatively consistent in all cases.

The type of relationship is exemplified in a study by Henry (3).

In this study, he used seventy-two undergraduate men and women to determine if a higher correlation might be found between the strength/mass ratio and the speed of limb motion. From an erect position, each subject swung his arm through an arc in a lateral adductive movement breaking a series of timing stations. Five or more learning trials were given and twenty official trials were taken to represent the individual's movement time (or strength-in-action) score. Static strength and arm mass measurements were taken, using a spring scale, in the testing position, i.e., the beginning position (0°) of the movement arc. The mean individual strength/mass ratios were correlated with individual mean speeds as determined from the cumulative times. The coefficients were all extremely low ($r = -0.02$; -0.09; 0.01; 0.04; 0.07). It should be observed that the reliability coefficients for the speeds, computed by the odd-even split-half techniques and converted to full test length, ranged from $r = 0.96$ to $r = 0.98$, and that the reliability of the strength/-mass ratio computed in the same manner was $r = 0.97$. These high coefficients denote the high reliability of individual differences in these items. The low coefficients between the variables signify high neuromotor specificity.

The correlations between individual differences in maximal limb speed and the static strength or strength/mass ratio measured in the movement position, as exemplified by Henry's study (3), have been found by many to be very low (1, 2, 4, 5, 6, 7, 8, 9, 10).

Some of these studies lead Henry and Rogers (11) to hypothesize the "Memory Drum" theory of neuromotor specificity. Later studies served as added support to this hypothese which states that all actions have

individual neural activating-response mechanisms (neuromuscular coordinating patterns) which are stored in the brain in a "memory drum" analagous to that of a computer. A certain set of stimuli causes a certain neural pattern to be established which elicits a specific response. These responses cannot be elicited by any other than the specific neural pattern and hence the reason for the low correlation between such items as reaction time-movement time and static strength-strength-in-action.

As previously mentioned, many studies have added support to this theory.

Rasch (10), in an attempt to determine the relationship existing between the speed of voluntary movements of the hand, forearm and arm and the weight, length and strength of these segments, explored the role of individual differences in strength. Using twenty-five subjects performing the lateral adductive arm swing, he measured the static strength at the beginning position of the movement plane (0°) and recorded the voluntary speed of movement through the lateral adductive arc. His results showed no statistically significant correlation between the speed of voluntary movement and the measured static strength.

Yet another study is by Clarke (4) who investigated the relationship of individual differences in arm speed, strength and mass in forty-eight subjects. His measures of static strength were also taken at the beginning position of the lateral adductive arm swing which was used to obtain the reaction time and movement time. The data revealed that knowledge of muscular strength could not be used to predict successfully the speed of an arm movement. The correlation between the strength/mass ratio and speed of movement was non-significant ($r = -0.277$). With arm mass

partialled out the correlation of static strength with speed of movement failed to reach statistical significance ($r = -0.369$). The high reliability of individual differences found supports the conclusion that the zero correlation coefficients indicate an extremely high specificity of "strengths".

An extension of these studies was undertaken by Smith (8) who investigated the general problem of securing a basic understanding of individual differences in such presumed functional entities as limb strength and limb speed and concluded that individual differences in the variables were highly specific. With seventy subjects, he collected data on the maximum speed and reaction latency of the lateral adductive limb movement. The static strength and effective arm mass scores were obtained in the beginning position of the movement arc. His results revealed that individual differences in all measures were highly reliable, and yet, almost without exception, these individual differences were highly specific to the limb, its direction of movement, its static strength, speed and reaction latency. For instance, the correlation coefficients reported between individual differences in speed of movement and measured static strength were only $r = 0.267$ and $r = 0.210$.

Similar results were obtained by Henry and Whitley (2) using sixty-five subjects. They endeavored to determine that the muscular force exerted in a movement made at maximum speed was determined by a separate neuromotor coordination pattern rather than by the static strength coordination pattern of the muscles involved. In their test, the measurement of speed of movement was taken as the time to adductively swing the arm at maximum speed in a lateral plane through a 90° arc. Arm mass and static strength was measured by a spring scale at the begin-

ning position of the movement arc. The results obtained indicated an almost complete absence of correlation between speed of arm movement (strenth-in-action) and static strength, again showing high neuromotor specificity of strength.

Whitley and Smith further substantiated the specificity of strength results in a study employing sixty subjects (1). They found high reliability coefficients for each variable, but extremely low and non-significant correlations between static strength and the maximum speed of movement ($r = -0.210$).

In summary, the weight of the evidence to date supports the high specificity of strength, leading to the hypothesis that there is not one strength, but many "strengths" involved in muscular activity even within the same group of muscles. At least two types of strength have so far been illustrated viz., the pre-movement static strength and the strength-in-action required for the movement of a limb.

<u>The Relationship Between Static Strength and Reaction Time</u>. Reaction time is the time required for the neural organization of a movement pattern, including the acceptance and interpretation of the activating stimuli, whereas exerted strength is the result of a co-ordinated neuro-muscular program.

Assessment of the neuromotor specificity theory (11) leads to the "a priori" hypothesis that only a low relationship is to be expected between the organization time for a particular program and the program itself.

A factorial analysis of individual differences in limb speed, reaction and strength was conducted by Henry et. al. (6), using one

hundred and fifty subjects from two separate groups. They found a non-significant correlation between static strength and speed of reaction ($r = 0.275$ and $r = 0.182$).

Glines (12) in a study using sixty-five 13-year old Medford study subjects, attempted to determine the relationships of reaction time, movement and completion time to strength and other anthropometrical measurements. He tested total body movement and reaction time, arm movement and reaction time and the static strength of a number of muscle groups (the arm included). Although the arm movement was dissimilar to that employed by the present study and those previously cited, the data revealed no statistically significant relationship between strength and reaction time.

An investigation to determine the relationships of reaction, movement and completion times with various strength and anthropometrical measures in 13-year old boys by Clarke and Glines (13) also failed to reveal a significant correlation between the static strength of the arm and speed of reaction ($r = 0.09$) using the same methods employed by Glines (12).

Pierson and Rasch (14), using twenty-six subjects in a weight training program to demonstrate the effect of increases in general arm strength on the speed of arm reaction found a non-significant correlation between strength and reaction time of $r = -0.23$.

Kerr (15) studied the relationship between changes in strength of the quadriceps muscles and changes in reaction time and movement time of a knee extension movement in forty-five subjects. The initial strength-reaction time correlation resulted in a significant relationship ($r = -0.375$).

However, when he separated his subjects into groups and then computed the strength-reaction time correlation at the three testing periods during the strength training program, he found a non-significant relationship.

Reaction Time-Movement Time Relationships. This area has received considerable attention by researchers in the past few years. The overwhelming evidence points clearly to the prescence of a high degree of item specificity with respect to these variables. Studies in this general area have recently been reviewed by Pierson (16). An example of these studies is that of Henry (17) reviewed below.

Of particular interest in the present study are those findings pertaining to reaction time and limb speed, especially horizontal adductive arm speed. Further, studies dealing with this particular aspect of movement time-reaction time research tend to be more recent and are therefore not included in previous reviews.

Also reviewed in this study are those occasional investigations that have reported the prescence of a substantial relationship between these variables.

The relationship of the reaction latency and the time required for basic limb movements made at maximal speed was explored by Henry (17) in a study using over four hundred subjects. The movements and stimuli were of varying types and complexity, including the lateral adductive movement to a light stimulus. He concluded that individual differences in speed of reaction and speed of movement were almost completely independent and uncorrelated in terms of the fundamental relationship ($r = 0.113$ to $r = -0.124$).

The hypothesis, by Henry (17), that correlations of approximately

zero between reaction time and movement time signified that the individual differences in these two variables were independent and unrelated was questioned by Pierson and Rasch (14). Although the movement was not of the lateral adductive type, Pierson and Rasch found a significant correlation of $r = 0.47$ between reaction time and movement time (14). Based on their results, they implied that a correlation of zero indicated zero relationship only in the case of a normal bivariate population.

In reply, Henry stated (18) that the postulation of a common mechanism for reaction time-movement time (R.T. - M.T.), vaguely described as "speed", suggests a prediction in which the fundamental R.T. - M.T. correlation should be high. In contrast, there are separate neurophysiological mechanisms for movement speed and for reaction speed; muscular force causes speed of a limb movement, whereas reaction latency reflects the time required for pre-movement operation of a Central Nervous System programming-switching mechanism. These concepts lead to the prediction that the fundamental R.T. - M.T. correlation should approach zero.

Henry supplimented his discussion with the results of testing one hundred and twenty subjects (18). The R.T. - M.T. correlation was non-significant ($r = 0.02$). The size of the correlation remained unchanged after the distribution of scores was corrected for skewness. Variance analysis of regression excluded non-linearity as the possible cause of the low correlation, thus justifying the conclusion that individual differences in reaction time and movement time are independant and unrelated under the conditions of the experiment.

The relationship between reaction time and movement time in the lateral adductive arm movement was studied by Slater-Hammel (19). His correlations

ranged between $r = -0.07$ and $r = 0.17$. He concluded that measurement of reaction time could not be readily used to predict speed of movement.

Cooper (20) also found no evidence of a correlation between reaction time and movement time ($r = 0.020$ and $r = 0.041$) as did Smith (21) with correlations ranging between $r = 0.157$ and $r = -0.43$.

Some evidence of a relationship between R.T. - M.T. has appeared occasionally in the literature.

Pierson (16) using an 11-inch forward movement of the arm with four hundred male subjects aged eight to eighty-three years disclosed a significant relationship ($r = 0.56$) between R.T. - M.T. for the total group. However, as shown by Mendryk (22), the heterogeniety factor in Pierson's sample (14) was the cause of the significant relationship. When this factor is accounted for (22), the R.T. - M.T. correlation becomes non-significant.

Using the same 11-inch forward movement, Youngen (23) found a significant correlation of $r = 0.26$ between the R.T. - M.T. variables for one hundred and twenty women athletes and non-athletes.

Kerr (15), using forty-five subjects, studied the relationship between changes in strength of the quadriceps muscles and changes in R.T. - M.T. in a knee extension movement. His results which showed a significant correlation between R.T. - M.T. of $r = 0.54$ and $r = 0.63$ were inadvertently affected by his methodological design and this factor may have accounted for the unusually high relationship found.

The majority of studies, using the lateral adductive arm swing, have clearly indicated the highly specific nature of both speed of

reaction and speed of movement with their results of a non-significant correlation (1, 2, 3, 4, 8, 9, 10, 17, 18, 24). However, in view of the fact that some studies have shown a significant correlation, the R.T. - M.T. relationship will again be observed in this study.

Comment. Although occasionally significant correlations do occur, and indeed are to be expected, the evidence in support of neuromotor specificity is not weakened. The extent of the relationship, as represented by the size of the correlation coefficient rather than the presence of a relationship as represented by levels of significance, is the important consideration. It should be pointed out that even where significant correlations as large as r = 0.60 are reported (15), the variance in common between the two variables is only 36 percent. The remaining variance is attributable to either item specificity or error. Where the reliability of individual differences in both variables is high, as it is in most studies cited, the majority of this residual variance is entirely item specific.

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CHAPTER III

METHODS AND PROCEDURES

Experimental Design. The subjects were fifty volunteer male students enrolled in the freshman required Physical Education service program at the University of Alberta. Each subject only attended one testing session of approximately one hour in length during which the following pertinent data was collected.

The effective arm mass of each subject was computed as the average of three seperate weighings taken with the subject seated and his right arm extended to the side. The static strength, measured at each of three points on the simulated movement arc (i.e., 0^{o}, 45^{o}, and 90^{o}) was then secured. The subject's strength score at each of these stations was the average of these separate determinations (1) each separated by a forty-five second rest. A two minute rest was given between the different testing stations on the arc.

The strength/mass ratio, construed as the effective static strength, was derived from dividing the effective arm mass into each of the static strength scores.

Strength-in-action, represented by the movement time, consisted of the average of twenty consecutive arm swings of the horizontal adductive movement pattern from side extension through 90^{o}. The twenty trials were preceded by five practice trials. There was a 45 second rest between trials.

All movement time trials were preceded by a reaction time to a light

stimulus. The reaction time was recorded coincidentally with each movement time and treated in the same manner.

Equipment. The equipment consisted of three separate items. One apparatus measured the effective arm mass, another measured static strength, and a third recorded reaction time and movement time.

The apparatus that measured the effective arm mass consisted of a chair, an adjustable microphone stand, a piece of two-by-four with a braced yardstick hinged to it, some cord and a calibrated spring scale (Figure 1.).

The spring scale was suspended from a fixed point and attached to the yardstick at the required position (i.e., the base of the fingers between the second and third fingers when the arm and hand were outstretched). The yardstick, hinged to the two-by-four was attached to the stand so as to allow for adjustments to the subject's specific height at the axilla when the subject was seated, weighed 125 grams. This weight was subtracted from the gross weight to produce the effective arm mass. This mass, measured in grams, was then converted to kilograms.

The static strength was measured by an apparatus constructed of a strong metal alloy. It consisted of a stabilizing support bracket; an upright, seven feet high, attached to the wall approximately three and one half feet from a corner and firmly braced; a reinforced metal arm attached to the upright in such a manner as to allow for height adjustment and rotation about the upright; a handle attached to the arm to allow for lateral adjustment from the upright; a cylinder mounted on the top of the handle through which a cable was threaded and which allowed for cable

length adjustments; a curved solid rod mounted on wall brackets that allowed for height adjustment and so situated that the circumference of the curved rod fitted the corner; moveable cable guides mounted on the rod at appropriate intervals; an angle iron anchor stanchion mounted on the wall below the curved rod; a cable that was threaded through the cylinder on the handle, over the curved rod via the cable guides and secured on the anchor stanchion by means of a hook through the appropriate hole (Figure 2.).

The apparatus was adjustable to allow for variations in a subject's shoulder height and arm length. This was necessary to maintain consistency of recording. When the cable was taut, it was required to be at right angles to the swinging arm regardless of the position of the arm (i.e., at 0^{o}, 45^{o}, or 90^{o} from side extension). The tension on the cable, produced by the effort of the subject, was recorded by a cable tensiometer, calibrated to the size of the cable, attached to the cable between the curved rod and the anchor stanchion. With the conversion graph (Appendix D), the units recorded were converted to kilograms.

The reaction time-movement time apparatus was also constructed from a strong metal alloy (Figure 6.). The apparatus was attached to a wall on either side of a wall pillar and consisted of: a weighted support stand attached to the wall by a hinged brace five feet long; a curved track and adjacent support rod attached to the stand by a clamp allowing for height adjustment; a wall bracket on the other side of the wall pillar which secured the other end of the track and rod but allowed for height variability; the support rod that had the same curvature as the track, but a radius two inches larger; Honeywell Standard Micro-switches of the

single pull double-throw type attached to the support rod at the appropriate intervals (i.e., 0°, 22.5°, 45°, 90°, and 112.5°); the track rubbed with graphite grease, one hundred and thirty centimeters long, consisting of 145° of a circle; a large hard-rubber stopper backed by a strong spring attached to the terminal end of the track to absorb the shock of the cylinder; a brass cylinder, which was the mass to be moved (made relatively frictionless by the graphite grease). A handle extended downward from the cylinder by which the subject could move the mass through the arc. A raised extension of the cylinder, sloped at either end and two inches long, was situated on the cylinder in such a manner that as it passed along the track, it forced the special arm of a particular micro-switch to close the circuit, stopping the appropriate chronoscope, thus recording (in one hundredths of a second) the elapsed time at that station.

A micro-switch at the beginning of the track (0°) was situated so that the raised portion of the cylinder kept the lever arm of the micro-switch closed. Any forward movement of the cylinder caused the switch to open immediately, thus breaking the circuit and stopping the timer, thereby recording reaction time. (In this experiment, the other micro-switches were placed at intervals of 22.5°, 45°, 90°, and 112.5° from the beginning position on the movement arc). Each micro-switch was connected, through a relay in the control panel, to a Standard Electric Type S-1 chronoscope which recorded the elapsed time in one hundredths of a second. These recordings were then interpolated to 0.001 second units.

The warning light (amber) and stimulus light (white) were mounted on a panel attached to a microphone stand. This was placed directly in front of the subject but outside the radius of the track.

FIGURE I. Testing Position For Effective Arm Mass Measurement.

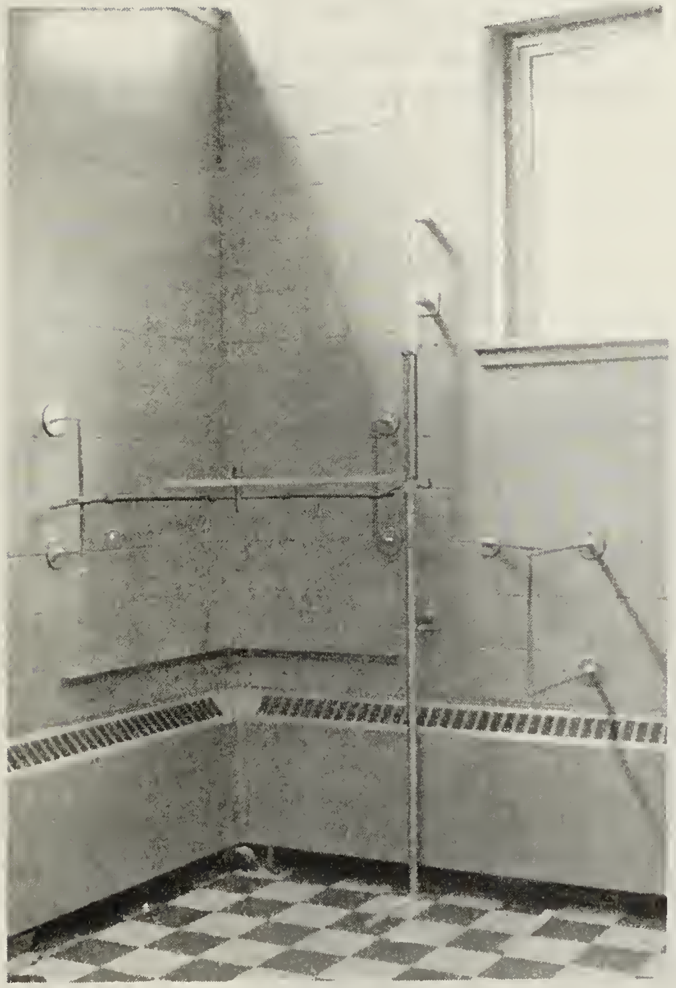

FIGURE 2. Static Strength Testing Apparatus

FIGURE 3. Testing Static Strength At 0° Position On Simulated Arc. Cable Tensiometer Not Shown.

FIGURE 4. Testing Static Strength At 45° Position On Simulated Arc. Cable Tensiometer Not Shown.

FIGURE 5. Testing Static Strength At 90° Position On Simulated Arc. Cable Tensiometer Not Shown.

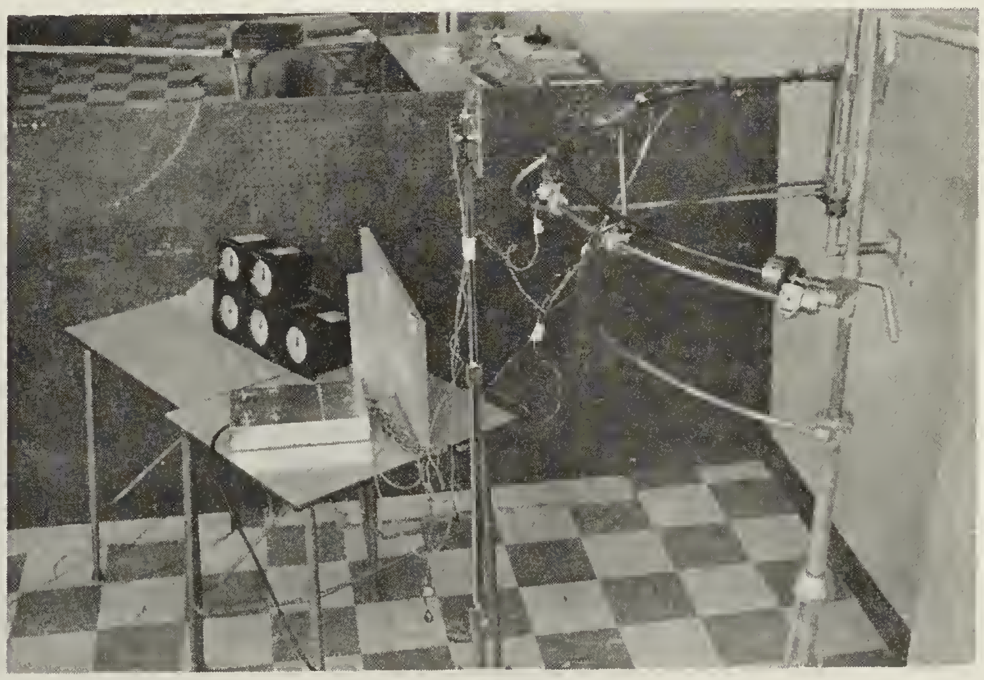

FIGURE 6. R.T. – M.T. Apparatus – Side View. Brass Cylinder Between Station II and Station III.

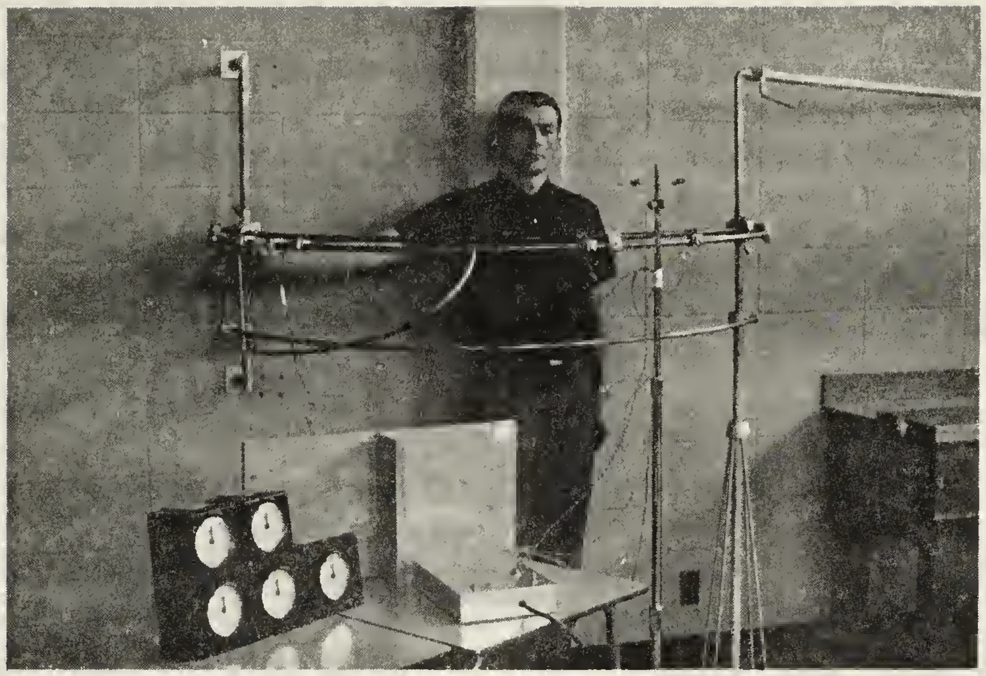

FIGURE 7. Beginning Position Awaiting Stimulus Light To Begin R.T. and M.T. Clocks.
Subject's Left Hand Should Be On Support Stand.

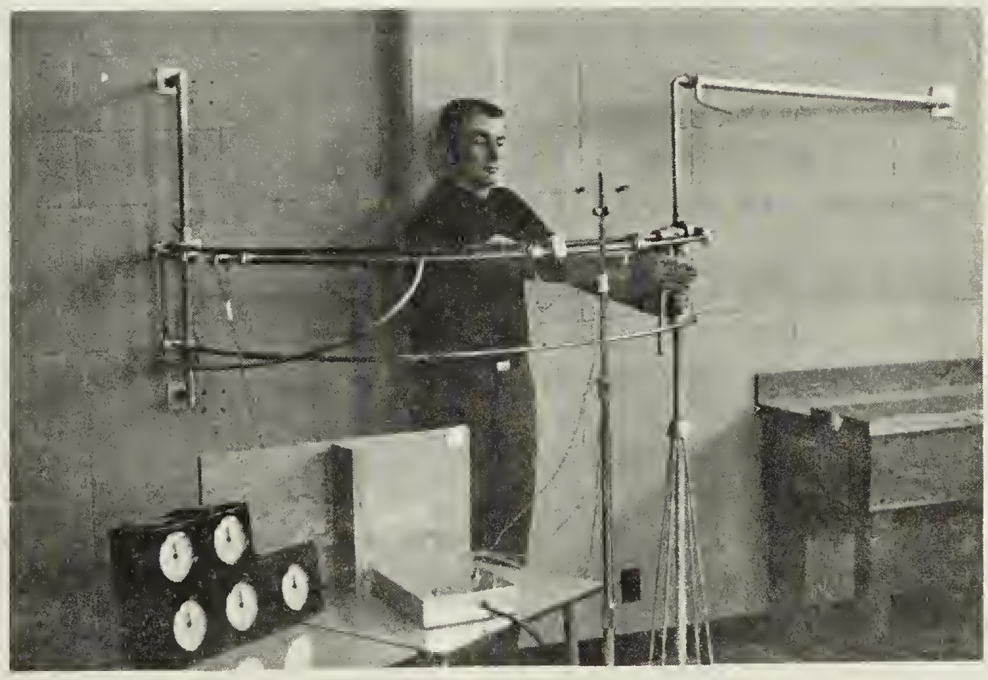

FIGURE 8. Terminal Position Of Movement Following Response To Stimulus Light.

The control panel consisted of a silent two-way master switch, an on-off switch and six relays. The relays connected the micro-switches to the chronoscopes via the master switch. The master switch was also used to vary the fore-period delay interval between the warning light and the stimulus light.

The recording instruments (i.e., the spring scale, the cable tension dynamometer and the five chronoscopes) were calibrated and their variance determined in the following manner: for the spring scale by recording twenty separate readings for each of a 650 gm. weight, a 1250 gm. weight and an 1825 gm. weight; for the dynamometer by recording fifty separate readings each of a 9.9 kgm. weight and of an 18.2 kgm. weight; for the chronoscopes by recording twenty-five trials, all clocks being started together from the control panel, and varying the recorded time from 19.1 hundredths of a second to 55.0 hundredths of a second.

The Test. When the subject reported for his testing session, he was familiarized with the equipment and a brief resumé of the procedure was given to him.

At station one, the mass of his right arm was measured. The subject seated himself with his back straight and his feet directly under his knees. The hinge joint of the weighing apparatus was adjusted to the appropriate height determined by having the subject raise both arms to side extension and keeping the shoulders level. The hinge joint was then raised until it fit snugly in the axilla of the arm to be weighed (in all cases the right arm). The free arm was lowered and the hand lightly grasped the seat of the chair. The arm to be measured was placed on the yardstick which was supported by a cord to the spring scale. The subject

was told to look straight ahead, close his eyes and completely relax the muscles of the arm and shoulder but not to let his back sag (Figure 1.). The procedure was repeated three times giving three separate readings which were averaged to produce the effective arm mass.

To measure static strength, the subject stood with his shoulder against the upright stand and his feet firmly braced on the floor. With his free (left) hand, he grasped the stabilizing bar at waist height. The swinging arm of the apparatus was adjusted to his shoulder height and the grip handle was adjusted to a point at the base of the fingers when the arm and hand were extended. Then at each of the three prescribed positions of 0° (Figure 3.), 45° (Figure 4.), and 90° (Figure 5.), he attempted to push the arm, keeping the elbow straight, in the direction of the arc. At each position, the score of the three measured trials was averaged to produce a static strength score (1). The actual contraction lasted about six to ten seconds with a forty-five second rest between contractions and a two minute rest between testing positions.

A total of nine static contractions was recorded for each subject resulting in three mean static strength scores, one for each position on the movement arc.

Upon completion of the static strength test, the subject proceeded to station three where his reaction time and movement time was recorded. He stepped behind the metal track, placed his back against the wall pillar and braced his feet. With his right hand he grasped the handle of the brass cylinder in the side extended position, with his left hand he grasped the support stand at waist height for stabilization (Figure 7.).

It was explained to him that upon the receipt of the light stimulus,

he was to swing the frictionless mass through the prescribed arc as quickly as possible. The spring and rubber stopper at the end of the track were pointed out with the explanation that he must hit them as hard as possible in order to have a qualifying score (Figure 8.). The explanation included the fact that his reaction time to the stimulus was recorded and that his speed of movement was recorded at the various intervals to ensure constant acceleration.

He was told that the amber light on the stimulus panel was only a warning light. When it came on, he knew that the stimulus light (white) was forthcoming. There was an inter-stimulus delay of one to four seconds to prevent anticipatory responses by the subject. When he saw the stimulus light, he swung the frictionless mass through the arc as fast as possible.

Upon completion of a trial, the subject had approximately forty-five seconds of rest during which time he returned the mass to the beginning position while the experimenter recorded the elapsed times at each station and reset the chronoscopes.

The subject was given twenty-five trials, the first five being discarded as practice trials and the remaining twenty used to compute the reaction time and movement time scores.

For each subject, the data collected was: three effective arm mass measurements; three static strength measurements at each of the three positions; twenty-five scores of reaction time and twenty-five scores of movement time at each of the four interval stations.

Statistical Analysis. The effective arm mass and the recorded static strength for each position on the simulated arc were combined to form a strength/mass ratio.

Reaction time and the movement times were computed from the average of the last twenty trials.

Reliability of individual differences of each variable was computed using the Pearson Product-Moment formula with the split-half technique (2:139) corrected to full test length with the Spearman-Brown prophecy formula (2:339).

The extent of a relationship, in terms of variance held in common between each of the variables, was computed using the Pearson Product-Moment method of correlation (2:139) and interpreting the resultant correlation coefficient as the squared "r" rather than in the unsquared form (3:129) was carried out.

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CHAPTER IV

RESULTS AND DISCUSSION

Results.

The following abbreviations are used in the results and discussion. Static strength will be referred to as "S.S.". The strength/mass ratio will be designated as S/M. Reaction time will be represented by R.T.. The movement time will be abbreviated to M.T. with the appropriate subletter to distinguish the movement phase and whether it is cumulative or interval movement time.

The Means and Standard Deviations of the Variables. The mean and standard deviation for age, height and weight are given in Table I. Note that the subjects were all reasonably uniform despite the fact that they were chosen on a strictly voluntary basis. The total number of subjects tested were fifty-three. Data from three of the subjects was discarded due to an injury reported at the end of testing in one case and illness reported by the other two. Therefore, fifty subjects were used as the sample in this study.

Table I
Mean and Standard Deviation of Age, Height and Weight

	Age (in years)	Height (meters)	Weight (kilograms)
Mean	19.60	1.750	72.30
S.D.	2.53	0.047	7.77

The means and standard deviations of the tested variables are shown in Tables II and III. In Table II, the results show the greatest

static strength (S.S.) scores recorded in position one, with position two recording the weakest and position three recording the intermediary scores. This is contrary to the theoretical hypothesis that the greatest amount of strength can be produced with the muscles acting at approximately right angles to the mass (as in position two at 45°). The advantage of the fulcrum behind the shoulder joint in position one may have accounted for the strength recorded in this position. Further investigation is required to extablish this point.

Table III shows the expected pattern of movement times. Note that M.T.c (the interval M.T. from 45° to 90°) appears slower than the other interval M.T.s. This is explained by the fact that this interval is twice as long (45°) as any of the others.

Table II
Mean and Standard Deviation of Static Strength, Arm Mass and the Strength/Mass Ratio

	S.S. 0°	S.S. 45°	S.S. 90°	Arm Mass	S/M 0°	S/M 45°	S/M 90°
Mean[a]	20.55	16.16	16.75	1.37	12.57	9.49	9.83
S.D.	4.41	3.74	3.41	.24	3.25	2.60	2.85

a. All measures are in kilograms.

Table III
Mean and Standard Deviation of Cumulative and Interval Movement Time and the Reaction Time

	R.T.	M.T. 1&a[a]	M.T.2[b]	M.T.3[b]	M.T.4[b]	M.T.b[c]	M.T.c[c]	M.T.d[c]
Mean[d]	19.79	11.76	17.94	29.57	33.77	6.18	11.67	4.10
S.D.	1.66	1.23	1.79	2.52	2.74	.57	1.14	.84

a. Both M.T.1 and M.T.a are identical being measured over the initial arc interval of 22.5°.
b. M.T.2, 3, 4 are the cumulative M.Ts. to 45°, 90°, and 112.5° respectively.
c. M.T.b, c, d are the interval M.Ts. between the stations on the arc.
d. All time measurements are in one hundredths of a second.

The Reliability Coefficient. The Pearson Product-Moment formula

employing the split-half technique was used to determine the extent of individual differences in each of the variables tested. The Spearman-Brown prophecy formula was then applied to the results to correct to full test length.

This analysis supplied reliability coefficients for all the tested variables. These reliabilities, shown in Tables IV and V, when corrected to full test length, produced an "r" greater than 0.90 in all cases but two involving interval M.T. (Table V). The M.T. reliabilities are calculated as the cumulated times at each station (i.e., M.T.1; M.T.2 etc.) and as isolated interval times between each station (i.e., M.T.a M.T.b etc.).

Table IV
Reliability Coefficient of Static Strength Tests
and the Effective Arm Mass Test

	S.S. 0°	S.S. 45°	S.S. 90°	Arm Mass
r^a	.956	.981	.986	.986
r^b	.905	.946	.949	.948

a. Reliability coefficients corrected to full test length N = 50, n = 3.
b. The single trial reliability coefficient N = 50, n = 1.

Table V
Reliability Coefficient of Reaction Time,
Cumulative and Interval Movement Times

	R.T.	M.T. 1&a[a]	M.T.2	M.T.3	M.T.4	M.T.b	M.T.c	M.T.d
r^b	.925	.939	.905	.953	.933	.852	.921	.843
r^c	.861	.885	.826	.911	.875	.742	.853	.729
r^d	.377	.409	.485	.506	.407	.223	.524	.203

a. The cumulative and interval M.Ts. at station one (22.5°) are identical.
b. The Spearman-Brown corrected reliability coefficient, N = 50, n = 20.
c. The split-half reliability coefficient N = 50, n = 10.
d. The single trial reliability coefficient N = 50, n = 1.

These reliability coefficients, when corrected to full test length,

are all sufficiently high to indicate that the number of trials used to measure each variable was sufficient to establish individual differences in each of the tested variables.

In the case of the reaction time (R.T.) and movement time (M.T.) reliability coefficients (Table V), the single trial reliabilities are computed to show the need for averaging twenty trials to approximate the individual's true score. This large number of trials is necessary in order to overcome the intra-individual unreliability of the subject on any single trial. This trial by trial variability is due to intrinsic subject response variability and not to variability in the testing instruments and observational technique of the experimenter. Table VI shows that the variability of the testing instruments or true measurement error variance is negligible. Its effect on the reliability coefficient would be non-existent.

Table VI
The Variability of the Recording Appartus

	Spring Scale grams	Chronoscope (seconds) R.T.	M.T.1	M.T.2	M.T.3	M.T.4	Dynamometer kilograms
S.D.	0.000	0.0014	0.0046	0.0018	0.0015	0.0016	.115

The Correlation Coefficient of Strength and Movement Time. The variance in common between two variables is determined by the computation of the correlation coefficient.

All the correlations of strength with movement time (M.T.) produced a negative result. This means that the slope of the curve (strength against movement) is negative showing that the stronger an individual, the faster is his M.T.. These results are shown in Table VII . The

correlations of the strength/mass ratio (S/M) and the M.T. are very low, in most cases not being significantly different from zero. The two correlations that are significant from zero are just barely so. All cases of static strength (S.S.) correlations with the M.T. are significantly different from zero.

Table VII
Correlation Coefficients of the Strength/Mass Ratio, Static Strength and Arm Mass with Reaction Time, and the Cumulative Movement Time[a]

	S/M 0°	S/M 45°	S/M 90°	S.S. 0°	S.S. 45°	S.S. 90°	Arm Mass
R.T.	.143	.087	.145	.019	.055	.012	.256
M.T.1	-.267	-.282	-.229	-.464	-.495	-.469	-.267
M.T.2	-.158	-.170	-.131	-.456	-.423	-.337	-.387
M.T.3	-.266	-.186	-.251	-.558	-.537	-.539	-.306
M.T.4	-.271	-.292	-.264	-.566	-.554	-.563	-.119

a. With 48 degrees of freedom, "r" is required to exceed ±.279 for significance at the .05 level of confidence.

In order to further pursue the relationship between strength and movement time, a correlation analysis was conducted on the S/M and S.S. with the interval M.T.. As shown in Table VIII, these results are very similar to the correlations with the cumulative M.T. (Table VII) where the S.S. correlations are significant from zero, but the S/M correlations are not.

Table VIII
Correlation Coefficients of the Strength/Mass Ratio, Static Strength, and Arm Mass with the Interval Movement Time[a]

	S/M 0°	S/M 45°	S/M 90°	S.S. 0°	S.S. 45°	S.S. 90°	Arm Mass
M.T.a	-.267	-.282	-.229	-.464	-.495	-.469	-.267
M.T.b	-.297	-.309	-.238	-.509	-.497	-.466	-.143
M.T.c	-.150	-.133	-.146	-.434	-.386	-.425	-.321
M.T.d	-.100	-.191	-.199	-.287	-.340	-.397	-.273

a. With 48 degrees of freedom, "r" is required to exceed ±.279 for significance at the .05 level of confidence.

It is notable that the same pattern of response is shown in both Table VII and Table VIII where the correlation of M.T. with S.S. is considerable larger than the correlation with the S/M. For all movement times (cumulative and interval), the averaged correlation, by the Fisher "z" transformation, for S.S. is $\bar{r}_z = -0.440$ whereas for S/M, $\bar{r}_z = -0.216$. The difference between the averaged correlations, $r_z = -0.224$, is statistically significant ($t_z = 4.15$:d.f. $= 11$).

<u>The Inter-correlations of Strength and Movement Time</u>. The inter-correlations coefficients of the S.S. and S/M are given in Table IX. In this table, the figures below the diagonal are the squared correlation coefficients and represent the amount of common variance between each of the various strength tests. Observe that as the testing positions become further apart, the correlation between positions becomes less. Also of interest is the low correlations evident between the S.S. and S/M where the only difference is the effective arm mass.

Table IX
Inter-correlation Coefficients of Static Strength Tests and the Strength/Mass Ratio Scores[a]

	S.S. 0°	S.S. 45°	S.S. 90°	S/M 0°	S/M 45°	S/M 90°
S.S. 0°	[b]	.818	.609	.762	.586	.422
S.S. 45°	.668		.773	.631	.840	.569
S.S. 90°	.370	.598		.492	.671	.698
S/M 0°	.581	.398	.242		.859	.738
S/M 45°	.343	.705	.452	.737		.908
S/M 90°	.178	.323	.486	.544	.822	

a. With 48 degrees of freedom, "r" is required to exceed $\pm.279$ for significance at the .05 level of confidence.

b. The figures below the diagonal are the squared correlation coefficients.

The inter-correlations in Table IX diminish as the angles of testing become further apart. Similarly, Table X shows that the interval M.T. inter-correlations also diminish as the angle between the intervals increases.

Table X
Inter-correlation Coefficients of Interval Movement Time[a]

	M.T.a[b]	M.T.b	M.T.c	M.T.d
M.T.a		.74	.66	.05
M.T.b	.549		.69	.19
M.T.c	.436	.486		.49
M.T.d	.003	.036	.241	

a. With 48 degrees of freedom, "r" is required to exceed $\pm .279$ for significance at the .05 level of confidence.

b. The figures below the diagonal represent the squared correlation coefficient.

The percent variance in common between two variables is derived by the squared correlation coefficient multiplied by 100. In the formula $r^2 + k^2 = 1$, $r^2 \times 100$ represents the percentage of the variance common to both variables and $k^2 \times 100$ represents the percentage of the variance specific to the variables themselves.

In Tables IX and X, eight out of twenty-two of the correlations have more than 50 percent of the variance in common.

<u>The Correlation Coefficients of Reaction Time and Movement Time.</u> The correlations between reaction time (R.T.) and both cumulative and interval movement time (M.T.) are all very low, being non-significant in all but one instance (Table XI).

Table XI
Correlation Coefficients of Reaction Time with Cumulative and Interval Movement Time[a]

	M.T.1&a[b]	M.T.2	M.T.3	M.T.4	M.T.b	M.T.c	M.T.d
R.T.	.027	-.090	-.021	-.014	.171	.051	-.324

a. With 48 degrees of freedom, "r" is required to exceed $\pm .279$ for significance at the .05 level of confidence.
b. Both M.T. and M.T.a are identical, being the first 22.5° interval on the movement arc.

Discussion.

Reliability Coefficients. In all cases, the reliability of individual differences was high, ranging from r = 0.91 to r = 0.99 (Tables IV and V). Single trial reliability was computed for all measures. The static strength and arm mass single trial reliabilities ranged from r = 0.90 to r = 0.95, indicating that the three trials of each test were sufficient to establish the role of individual differences in these tests. The single trial reliabilities for reaction time (R.T.) and the recorded movement times (M.T.) ranged from r = 0.20 to r = 0.51, which indicated the inability of the subjects in maintaining their order within the group on subsequent trials. This fact was established by the high reliability of individual differences found when using the twenty trials (Table V), and by the almost non-existent measurement error variance (Table VI). It is apparant that while individual differences exist on the basis of a subject's ability, as represented by an approximation of his true score, they do not exist to any apparant degree when the subject's single trial performance is taken as the measure of his speed of movement response.

Static Strength-Movement Time Correlation Analysis. The many inves-

tigators who have explored the area of specificity of "strengths" agreed on the conclusion that the strength/mass ratio (S/M) or the pre-movement static strength (S.S) could not be used to effectively predict the strength-in-action represented by the movement time (1, 2, 3, 4, 5, 6, 7, 8). In other words, neither the S/M nor the S.S. score correlate highly with the recorded M.T.. This conclusion was also drawn in the light of the present data. The strength-in-action, measured as the M.T. to 90°, correlated with the S/M at 0° on the movement arc r = -0.266 and with the S.S. at 0° r = -0.558. The negative sign signifies an inverse relationship and this has been found in all studies of this type. What these correlations implied was that, in the case of the strength/-mass ratio (S/M), 7.1 percent of the individual difference variance in the S/M was accounted for by the individual differences in movement time (M.T.) to 90° leaving 92.9 percent of the variance specific to the tasks. Similarly, in the static strength-movement time (S.S. - M.T.) correlation, 31.4 percent of the individual difference variance was common to both variables while 68.6 percent was task specific.

The previous studies, however, only tested the static strength (S.S.) at the beginning position of the prescribed arc (0°). This study was designed to observe the correlation of the cumulated M.T. at 90° with S.S. measured at 45° and 90° on the movement arc. The resulting correlations (Table VII) were similarly low, being r = -0.186 and r = 0.251 for the S/M at 45° and 90° respectively and r = -0.537 and r = -0.539 for S.S. at 45° and 90° respectively.

A similar low relationship was observed with the S/M and S.S. tests when correlated with the cumulative M.T. to the various timing stations established at 22.5°, 45°, 90° and 112.5° on the movement arc (Table VII).

These results would appear to establish beyond doubt the specific nature of the two types of strength. However, to avoid the argument that corresponding segments of the movement time phase and the S.S. tests may have been related, a correlation analysis was carried out on the same S/M and S.S. score results with the interval or phase movement time.

The resulting correlations, although slightly larger than those using the cumulative M.T., showed the same basic pattern, with none of the correlations indicating less than two thirds specificity (Table VIII).

These results lead to the conclusion that static strength, measured at any point on the movement pattern, could not be used to predict the strength-in-action at any point on the same movement pattern as defined in the experiment.

It is interesting to note the effect the measured arm mass had on the above-mentioned correlations. Although the effective arm mass correlated negatively with M.T. recordings indicating that the heavier the arm, the faster the M.T., the correlations were not appreciably significant from zero, leaving a great deal of the relationship specific to the variables (Tables VII and VIII).

Regardless of its effect (which appears to be ballistic) on the strength-in-action, the effective arm mass did have a significant effect on the S.S. correlations with M.T..

The averaged correlations of the S/M with M.T., by the Fisher "z" transformation (9:241), were significantly smaller than the averaged correlations of the S.S. with the M.T. ($t_z = 4.15$: df = 11). This meant that the effective mass of the arm had a depressing effect on the strength-

movement correlation to the point that the S/M correlation was non-significant whereas the S.S. correlation was significantly greater than zero. (Tables VII and VIII).

Although the difference between the S/M and S.S. correlations was non-significant in Clarke's results (1), he observed the same type of depressing effect of the correlation and attributed it to the arm mass. The present writer agrees with Clarke (1) when he suggested that no logical reason could be offered for the finding of a significant correlation between static strength (S.S.) and movement time (M.T.) and not for the strength/-mass ratio (S/M). Possibly it is due to the fact that the speed of movement, although directly proportional to the force applied to the mass, is inversely proportional to the mass itself.

Further investigation in this area involving the mass, as suggested by Whitley and Smith (7), may prove beneficial to a better understanding of the role of muscular action in different strength performances.

Strength Inter-correlations. Observation of the inter-correlations of the static strength (S.S.) scores taken at the three tested positions on the movement arc lead to some interesting facts.

The design of the study resulted in S.S. being measured for the same muscle group, that is the muscles that horizontally adduct the extended arm, at three different positions on the movement arc. When the scores taken at these positions were inter-correlated, it was found that the further apart the testing positions were, the more specific the S.S. became to the position tested. The correlation between the S.S. at 0° and S.S. at 90° was $r = 0.609$ which leaves 63 percent of the variance

($k^2 = 1 - r^2$) specific to the tested position.

As the testing stations approach each other with respect to angular position on the movement arc, the correlations increased, but still left a large amount of the variance specific, especially between S.S. at 45° and S.S. at 90° where $r = 0.773$ ($k^2 = 40$ percent:Table IX).

Although all the inter-correlations were significantly different from zero, there was evidence, within the scope of this study, that static strength was highly specific to the position in which it was tested.

<u>Reaction Time Correlations</u>. As was expected, the statistical analysis found little or no common variance between the raw S.S. scores or the S/M and the speed of reaction from a light stimulus. The correlations ranged from $r = -0.055$ to $r = -0.145$ (non-significant).

Contrary to the indications supplied by the findings of Pierson (10), Tuttle and Westerlund (11), and Kerr (12), it was found that the correlations between reaction time (R.T.) and movement time (M.T.) were extremely low which finding supports the theory of the highly specific nature of these variables as hypothesised by Henry (3, 13, 14, 15), Clarke (1), Whitley and Smith (8) and others (5, 16, 17, 18).

The correlations computed between R.T. and both cumulative and interval M.T. ranged from $r = 0.171$ to $r = -0.324$ Table XI). The largest correlation ($r = -0.324$) was between R.T. and the interval M.T. from 90° to 112.5° and was significantly different that zero. There may be some actual relationship involved as it appeared that this section of the movement arc was completed in the fastest time (Table IV), hence the quicker the R.T., the slower an individual could move between 90° and 112.5° on

the lateral adductive movement arc. For the time being, however, it is believed that this correlation was due to chance, and it is left to future investigation to lend credence to the possiblity of a relationship.

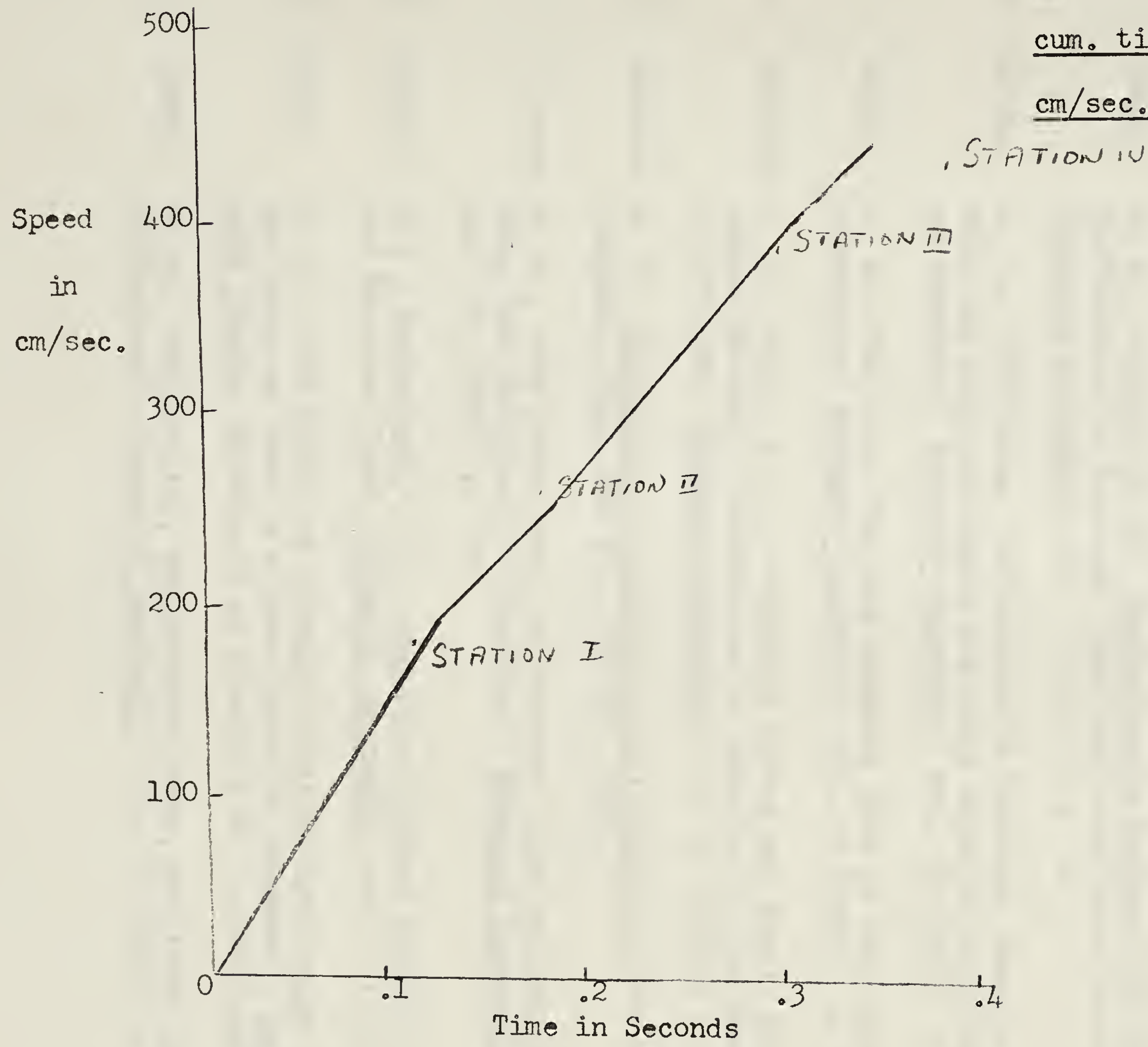
Movement Time Inter-correlations. An interesting development arose when inter-correlations were computed on the interval M.T. (Table X). From these results, ranging from r = 0.05 to r = 0.74, it appeared that "strength-in-action", represented by the M.T., was specific to the point at which it was measured (representing a segment of the arc). Further, it seemed that as the correlated M.T. sections became farther apart, the correlations decreased in size, as was the case with the static strength (S.S.) scores. Although all but two of the correlations were statistically significant (Table X), only in one correlation (between M.T.a and M.T.b) did the variance generality exceed 50 percent of the individual variance accounted for. This infers that strength-in-action is also highly specific to the position in which it is tested.

Whitley and Smith (9) support this observation when they reported the appearance of two phases of movement in the horizontal adductive arm swing. One phase appeared to approximately encompass the first 40° on the movement arc while the second phase of the movement was observed over the remaining distance.

Although the velocity curve plotted from the results of this study (Figure 9) compared almost identically with that plotted by Whitley and Smith (9), the inter-correlations of the interval M.T. lead to the belief that there are more than two phases of movement, and as the movement time (M.T.) represents strength-in-action, it may be a fact that strength-in-action is highly specific.

Figure 9. Acceleration curve for movement over an arc 140.97 cm. long with timing stations at 22.5°, 45°, 90° 112.5°

	M.T.1	M.T.2	M.T.3	M.T.4
cm. to	21.59	43.16	111.76	140.97
cum. time	.118	.179	.296	.338
cm/sec.	182.97	241.23	377.57	417.07



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CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the relationship between the effective static strength (represented by the strength/-mass ratio) of the right arm computed at the designated positions of 0°, 45°, and 90° on the movement arc and the strength-in-action of this limb (represented by the movement time through 90° of the same arc). The movement arc was the horizontal (lateral) adductive arm swing from side extension through 140°.

Observations were also made on the interrelationships of the measured static strength scores, the relationship between static strength scores and the reaction time, and the relationship between the movement time and reaction time.

Fifty male students enrolled in the University of Alberta required Physical Education service program were used as subjects. These subjects were chosen on a voluntary basis.

There was one testing period of an hour per subject. During this period, the effective mass of the arm was measured; three static strength scores were then recorded using a cable tensiometer set at each of the three testing positions on the simulated movement arc (i.e., at 0°, 45°, and 90°); and finally the subject performed twenty-five trials of the horizontal (lateral) adductive arm movement. This movement allowed for the recording of reaction time to a light stimulus and cumulative and interval movement times at 22.5°, 45°, 90° and 112.5° on the movement

arc.

On the basis of the statistical analysis and within the limitations of the study, the following conclusions seem justifiable:

1. There was a non-significant correlation between strength-in-action and the strength/mass ratio at all testing positions.
2. Although significant, the relationship between static strength and strength-in-action is low. The amount of individual difference variance specific to the type of strength measured is approximately four times greater than the amount of general variance.
3. The averaged correlations between static strength and strength-in-action were significantly larger than the averaged correlations between strength-in-action and the strength/mass ratio.
4. The inter-correlations of static strength scores obtained at 0°, 45° and 90° were significant. It was observed, however, that the amount of variance specific to the scores increased from 33 percent to 63 percent as the angular proximity of the testing positions increased.
5. Reaction time did not correlate significantly with the static strength scores or strength/mass ratios.
6. In agreement with previous research findings, no relationship was found between speed of reaction and speed of movement.

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APPENDIX

APPENDIX A

STATISTICAL TREATMENT

The Pearson Product-Moment formula was slightly modified to allow the use of a Numro-matic Calculator #1500. The following formulas were set up to accomodate this type of calculator.

Reliability Coefficient (by the calculator)

Split-Half A[a]	cross product	Split-Half B[a]
Σx_1 $\quad$ Σx_1^2	$\Sigma x_1 x_2$	Σx_2 $\quad$ Σx_2^2
$\Sigma x_1/N$ $\quad$ $\Sigma x_1^2/N$	$\Sigma x_1 x_2/N$	$\Sigma x_2/N$ $\quad$ $\Sigma x_2^2/N$
$\sigma x^2_1 = \Sigma x_1^2/N - (\Sigma x_1/N)^2$		$\sigma x^2_2 = \Sigma x^2_2/N - \Sigma(x_2/N)^2$
$\sigma x_1 = \sqrt{\sigma x^2_1}$		$\sigma x_2 = \sqrt{\sigma x^2_2}$

$$r_{x_1 x_2} = \frac{\Sigma x_1 x_2/N - [\Sigma x_1/N]\,[\Sigma x_2/N]}{(\sigma x_1)\,(\sigma x_2)}$$

Spearman-Brown correction for full test length:

$$\text{corrected } r_{x_1 x_2} = \frac{2\,(r_{x_1 x_2})}{1 + r_{x_1 x_2}}$$

a. $N = 25$

The single trial reliability is calculated using:

$$r_{s x_1 x_2} = \frac{\sigma t^2}{\sigma t^2 + [(\sigma w/_i{}^2)(n)]}$$

when $\sigma t^2 = \Sigma x_1 x_2/N - [(\Sigma x_1/N)(\Sigma x_2/N)]$

and $\sigma w/_i{}^2 = [\sigma x^2_1 + \sigma x^2_2/2] - \sigma t^2$

The correlation coefficient determined by the calculator:

Variable x[a]	cross product	Variable y[a]
Σx $\quad$ Σx^2	Σxy	Σy $\quad$ Σy^2
$\Sigma x/N$ $\quad$ $\Sigma x^2/N$	$\Sigma xy/N$	$\Sigma y/N$ $\quad$ $\Sigma y^2/N$
$\sigma x^2 = \Sigma x^2/N - (\Sigma x/N)^2$		$\sigma y^2 = \Sigma y^2/N - (\Sigma y/N)^2$
$\sigma x = \sqrt{\sigma x^2}$		$\sigma y = \sqrt{\sigma y^2}$

$$r_{xy} = \frac{\Sigma xy/N - [(\Sigma x/N)\,(\Sigma y/N)]}{(\sigma x)(\sigma y)}$$

a. $N = 50$

APPENDIX B

INDIVIDUAL SCORE SHEET

NAME ____________________ PHONE ____________________

AGE ____________ HEIGHT ____________ WEIGHT ____________

ARM MASS	STATIC STRENGTH 0°	45°	90°
1	1		
2	2		
3	3		
S	S		
$\bar{X}$	$\bar{X}$		

	RT	MT_1	MT_2	MT_3	MT_4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
S_x					
$\overline{X}$					
S_{x_1}					
$\overline{X}_1$					
S_{x_2}					
$\overline{X}_2$					

APPENDIX C

RAW SCORES

N	Age	N	Weight	N	Height
1.	18	1.	154.5	1.	69.75
	18		150.0		70.25
	18		181.5		70.75
	20		131.0		68.0
5.	18	5.	181.5	5.	67.0
	20		160.5		68.25
	18		173.5		69.0
	19		143.0		67.50
	18		152.5		66.50
10.	20	10.	169.0	10.	70.25
	19		129.0		65.25
	20		144.0		73.50
	24		157.0		68.25
	20		198.0		71.25
15.	18	15.	146.0	15.	70.0
	19		179.0		70.0
	21		164.0		69.25
	20		178.0		67.75
	18		133.5		65.25
20.	18	20.	171.0	20.	69.50
	19		171.5		69.25
	20		158.0		72.25
	18		140.5		66.50
	20		150.0		68.75
25.	18	25.	170.0	25.	67.50
	18		152.0		66.75
	32		141.5		67.25
	18		159.5		71.0
	20		169.5		70.25
30.	18	30.	156.0	30.	71.0
	19		158.0		66.75
	21		144.0		68.50
	25		169.0		70.25
	18		168.0		65.00
35.	20	35.	138.0	35.	68.25
	18		180.5		72.50
	17		165.5		69.0
	24		189.5		73.0
	17		130.5		68.25
40.	18	40.	160.0	40.	68.75
	20		156.5		68.50
	17		123.0		67.25
	21		148.0		67.25
	20		184.0		69.25
45.	24	45.	168.5	45.	67.75
	20		182.0		67.50
	20		158.0		68.25
	18		134.5		65.25
	21		172.0		72.25
50.	19	50.	160.0	50.	68.00

Effective Arm Mass in Kg.	Static Strength Scores in pounds		
	S.S. 0°	S.S. 45°	S.S. 90°
1. 1.66	1. 10.4	1. 10.3	1. 10.8
1.45	16.8	10.9	10.5
1.60	20.0	17.3	12.3
0.68	8.6	8.2	9.1
5. 1.23	5. 21.4	5. 18.3	5. 18.1
1.26	15.5	10.8	11.2
1.43	19.2	15.0	13.5
1.34	11.8	7.7	9.2
1.21	12.3	9.7	9.9
10. 1.35	10. 9.8	10. 8.5	10. 9.5
1.11	16.5	11.5	11.9
1.09	15.0	9.1	8.2
1.17	14.4	10.5	8.2
1.93	18.8	12.3	16.4
15. 1.31	15. 10.8	15. 9.4	15. 9.4
1.28	19.8	16.0	17.8
1.64	16.5	10.9	10.5
1.29	18.2	19.6	18.7
1.14	16.7	11.8	10.6
20. 1.47	20. 18.7	20. 13.9	20. 17.5
1.05	14.1	10.9	9.8
1.33	16.5	10.0	11.4
0.88	10.8	7.9	8.2
1.15	9.6	9.5	18.0
25. 1.15	25. 20.4	25. 17.8	25. 17.8
1.04	16.0	10.9	13.7
1.23	15.0	10.4	10.5
1.22	11.4	9.1	9.6
1.14	15.0	14.6	14.9
30. 0.93	30. 18.4	30. 11.2	30. 11.8
0.99	17.3	11.0	11.1
1.03	10.5	8.7	9.1
1.60	15.9	9.6	11.2
1.00	16.4	15.0	18.4
35. 1.02	35. 12.9	35. 10.0	35. 10.6
1.20	16.8	11.2	15.9
1.31	16.9	9.6	10.0
1.28	29.0	19.2	18.6
0.88	10.5	8.9	10.9
40. 1.33	40. 20.1	40. 13.3	40. 10.8
1.42	15.9	12.7	13.6
1.17	9.3	8.2	9.6
1.29	14.6	11.2	9.7
1.47	11.4	9.7	9.3
45. 1.19	45. 12.3	45. 8.4	45. 9.4
1.12	13.2	9.3	11.3
1.13	14.2	11.7	10.9
1.17	16.3	10.3	13.7
1.79	17.3	11.5	11.3
50. 1.33	50. 21.8	50. 16.9	50. 14.1

	S/M 0°		S/M 45°		S/M 90°		Reaction Time (in 100ths of a second)
1.	6.3	1.	6.2	1.	6.5	1.	18.6
	11.6		7.5		7.3		18.7
	12.5		10.8		7.7		20.1
	12.6		12.0		13.3		19.2
	17.4		14.8		14.7		18.6
	12.3		8.6		8.9		20.9
	13.4		10.5		9.4		21.4
	8.8		5.7		6.8		19.4
	10.2		8.0		8.2		19.0
	7.3		6.3		7.0		19.1
	14.8		10.3		10.7		18.7
	13.8		8.4		7.5		18.4
	12.3		9.0		7.0		18.5
	9.7		6.4		8.5		16.1
	8.3		7.2		7.2		19.4
	15.5		12.5		13.9		20.1
	10.0		6.7		6.4		21.3
	14.1		15.2		14.5		19.4
	14.6		10.3		9.3		19.0
	12.7		9.4		11.9		22.5
	13.4		10.4		9.3		18.6
	12.4		7.5		8.6		21.4
	12.3		9.0		9.4		24.3
	8.4		8.2		7.1		20.3
25.	17.7	25.	15.5	25.	15.4	25.	18.1
	15.4		10.5		13.1		20.1
	12.2		8.5		8.5		20.4
	9.3		7.4		7.9		20.3
	13.2		12.8		13.1		20.9
	19.8		12.0		12.7		20.0
	17.4		11.1		11.2		20.3
	10.2		8.4		8.8		21.5
	10.0		6.0		7.0		19.9
	16.4		15.0		18.4		20.5
	12.7		9.8		10.4		24.5
	14.0		9.3		13.3		21.0
	13.0		7.3		7.6		18.7
	22.7		15.0		14.5		22.5
	11.9		10.1		12.4		20.5
	15.1		10.0		8.1		19.9
	11.2		9.0		9.6		17.6
	8.0		7.0		8.2		18.0
	11.3		8.6		7.5		18.2
	7.8		6.6		6.4		20.5
	10.3		7.0		7.9		20.5
	11.8		8.3		10.1		19.0
	12.6		10.4		9.7		19.6
	13.9		8.8		11.7		18.2
	9.7		6.4		6.3		19.4
50.	16.4	50.	12.7	50.	10.6	50.	17.2

Cumulative Movement Time to the Various Stations on the Movement Arc

	$MT_{1\&a}(22.5^{o})$		$MT_2(45^{o})$		$MT_3(90^{o})$		$MT_4(112.5^{o})$
1.	11.9	1.	18.6	1.	31.1	1.	35.6
	11.7		17.5		29.4		33.6
	11.6		17.9		30.0		34.7
	13.3		20.6		33.8		37.8
	10.7		15.7		26.3		30.1
	11.7		17.9		29.2		33.3
	10.7		16.1		26.5		30.1
	13.9		20.3		32.3		36.0
	12.7		18.6		28.4		32.2
	12.6		19.3		31.5		35.5
	11.3		17.2		29.5		34.1
	12.5		18.9		31.2		36.2
	12.3		19.0		30.5		34.7
	10.1		16.0		26.8		30.4
	10.6		16.4		27.9		32.3
	10.9		16.1		27.3		31.7
	10.7		17.6		27.0		30.8
	11.2		16.9		27.8		31.4
	11.8		17.8		30.8		35.5
	9.9		15.7		26.2		29.9
	10.6		16.8		28.9		34.1
	10.7		16.9		28.7		33.7
	12.0		18.7		31.3		35.3
	12.2		18.4		30.0		34.0
25.	9.9	25.	15.7	25.	27.4	25.	32.0
	11.2		17.1		27.4		31.9
	11.8		18.0		30.8		34.9
	13.8		21.1		33.1		36.6
	12.7		19.0		32.1		36.1
	15.0		22.2		36.2		40.4
	11.3		17.6		29.6		34.4
	13.3		20.3		34.2		39.5
	10.5		16.3		27.7		32.0
	11.7		17.5		28.4		32.2
	13.5		19.9		33.1		37.3
	10.5		16.7		25.6		29.3
	12.1		18.1		29.2		33.1
	9.7		14.9		23.9		27.3
	11.7		17.8		29.3		33.3
	10.1		16.1		27.0		30.4
	12.6		18.8		29.6		33.8
	12.6		19.3		32.1		36.8
	12.7		19.4		31.9		37.0
	11.3		19.3		27.9		31.8
	13.0		15.6		31.7		36.3
	11.5		18.6		29.0		33.8
	12.2		17.0		29.1		33.1
	12.0		21.8		30.9		35.5
	13.9		14.1		32.8		36.6
50.	10.4	50.	20.5	50.	26.6	50.	30.3

Interval Movement Time (M.T.a and M.T.1 are identical)

	$MT_b(MT_2-MT_1)$		$MT_c(MT_3-MT_2)$		$MT_d(MT_4-MT_3)$
1.	6.7	1.	12.5	1.	4.5
	5.8		11.9		4.3
	6.3		12.0		4.7
	7.3		13.3		4.0
	5.1		10.6		3.8
	6.3		11.4		4.1
	5.5		10.4		3.6
	6.4		12.0		3.7
	5.9		9.8		3.8
	6.8		12.0		4.0
	6.1		12.3		4.6
	6.4		12.3		5.0
	6.7		11.5		4.2
	6.0		10.8		3.7
	5.9		11.6		4.4
	5.3		11.2		4.5
	6.1		10.4		3.8
	5.9		11.4		3.6
	6.0		13.0		4.7
	6.0		10.5		3.7
	6.3		12.1		5.2
	6.2		11.9		5.0
	6.7		12.7		4.0
	6.2		11.7		4.0
	5.9		11.7		4.6
25.	5.8	25.	10.4	25.	4.4
	6.3		12.8		4.1
	7.3		12.0		3.5
	6.3		13.2		4.0
	7.2		14.1		4.2
	6.3		12.0		4.9
	7.1		14.0		5.3
	5.8		11.4		4.3
	5.8		11.0		3.8
	7.0		13.3		4.1
	6.4		8.9		3.7
	6.0		11.2		3.9
	5.3		9.1		3.4
	6.2		11.5		4.0
	5.5		11.0		3.4
	6.2		10.8		4.2
	6.7		12.8		4.8
	6.8		12.5		5.1
	6.2		10.4		4.0
	6.2		12.5		4.6
	5.7		11.9		4.8
	5.8		11.1		4.0
	6.3		12.6		4.6
	6.8		12.2		3.9
50.	5.9	50.	10.3	50.	3.8

APPENDIX D

CONVERSION GRAPH FOR CABLE TENSION DYNAMOMETER

Conversion Graph for Cable Tensiometer Using 1/16th" riser